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Understanding misunderstandings in invasion science: why experts don't agree on common concepts and risk assessments

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Abstract

Understanding the diverging opinions of academic experts, stakeholders and the public is important for effective conservation management. This is especially so when a consensus is needed for action to minimize future risks but the knowledge upon which to base this action is uncertain or missing. How to manage non-native, invasive species (NIS) is an interesting case in point: the issue has long been controversial among stakeholders, but publicly visible, major disagreement among experts is recent.

To characterize the multitude of experts' understanding and valuation of non-native, NIS we performed structured qualitative interviews with 26 academic experts, 13 of whom were invasion biologists and 13 landscape experts. Within both groups, thinking varied widely, not only about basic concepts (e.g., non-native, invasive) but also about their valuation of effects of NIS. The divergent opinions among experts, regarding both the overall severity of the problem in Europe and its importance for ecosystem services, contrasted strongly with the apparent consensus that emerges from scientific synthesis articles and policy documents. We postulate that the observed heterogeneity of expert judgments is related to three major factors: (1) diverging conceptual understandings, (2) lack of empirical information and high scientific uncertainties due to complexities and contingencies of invasion processes, and (3) missing deliberation of values. Based on theory from science studies, we interpret the notion of an NIS as a boundary object, i.e., concepts that have a similar but not identical meaning to different groups of experts and stakeholders. This interpretative flexibility of a concept can facilitate interaction across diverse groups but bears the risk of introducing misunderstandings. An alternative to seeking consensus on exact definitions and risk assessments would be for invasive species experts to acknowledge uncertainties and engage transparently with stakeholders and the public in deliberations about conflicting opinions, taking the role of honest brokers of policy alternatives rather than of issue advocates.

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Keywords
Alien, biosecurity, concept, conservation, exotic, expertise, invasion, impact, management, native, non-native, uncertainty, risk, stakeholder, valuation

Introduction

To judge from the biological conservation literature, there is a general consensus that invasions of non-native species per se pose major risks to biodiversity and ecosystem services (Mack et al. 2000, Millennium Ecosystem Assessment 2005, Mooney et al. 2005, Vilà et al. 2010, Simberloff et al. 2013). However, this view is increasingly being challenged by experts (Davis et al. 2011) and it is debated whether invasive species are a main driver of species extinctions (Gurevitch and Padilla 2004, Clavero and García-Berthou 2005). Because ecological as well as other environmental and human-driven processes interact in complex ways, it can be difficult to determine whether invasive species are indeed a driver of environmental change or merely a symptom of some other events (Didham et al. 2005, Kueffer et al. 2013). Furthermore, the positive values of non-native species for conservation are increasingly discussed in the literature (Ewel and Putz 2004, Kueffer and Daehler 2009, Kueffer et al. 2010, Goodenough 2011, Schlaepfer et al. 2011), triggering critical responses (e.g., Vitule et al. 2012, Richardson and Ricciardi 2013). Then again, native species are sometimes considered to be invasive (Valéry et al. 2009, Carey et al. 2012) in disagreement with standard definitions (Richardson et al. 2011). These conflicting perspectives on invasive organisms and their effects on ecosystems can impede conservation action. This is particularly true if policies build on preventative measures on the grounds that an early response is likely to be more effective than a later cure (Leung et al. 2002, Hulme 2009). Such types of conservation actions rely on a general consensus among experts and stakeholders on the potential future negative impacts of non-native, invasive species (NIS).

It is therefore important to understand how perceptions about the effects of biological invasions and the need for management are shaped among stakeholders (affected interest groups) and experts (a person with a high degree of knowledge of a subject that is acknowledged by society, which leads to the attribution of a special role to the person in certain decision-making situations, Mieg 2009).

There has been some work on how stakeholders and the general public perceive the risks and consequences of biological invasions, and the appropriate management options to be taken (Bardsley and Edwards-Jones 2006, Binimelis et al. 2007b, Bremner and Park 2007, Fischer and van der Wal 2007, Garcia-Llorente et al. 2008, Andreu et al. 2009, Selge and Fischer 2010, Rotherham and Lambert 2011, Selge et al. 2011, Young and Larson 2011, Gozlan et al. 2013, Kueffer 2013). These studies show that learning about scientific facts related to effects of NIS is just one factor determining attitudes and opinions. Attitudes of stakeholders can also be influenced by the social context (Bremner and Park 2007, Fischer and van der Wal 2007, Garcia-

Llorente et al. 2008), differences in value judgments (e.g., emotional connectedness towards a species or towards specific management methods, Fischer and van der Wal 2007), conflicts of interest (e.g., managers vs. visitors of public parks, Garcia-Llorente et al. 2008), and the various roles that humans play in promoting invasions (McNeely 2001, Selge and Fischer 2010, Rotherham and Lambert 2011, Selge et al. 2011). Importantly, these studies suggest that stakeholders often differ strongly from experts and among themselves in their attitudes to invasive species and their willingness to participate in management actions (Bardsley and Edwards-Jones 2006, Andreu et al. 2009).

Less is known about how individual experts or expert communities differ in their perception and assessment of invasion processes, but there are indications that opinions do vary (Young and Larson 2011) and may be influenced by factors other than scientific facts (Selge et al. 2011). Indeed, it can be expected that in situations where facts and values are highly uncertain, as in the case of biological invasions, expert assessment also becomes highly dynamic and uncertain (Funtowicz and Ravetz 1993), and the influence of intuitions, ideologies and values is more pronounced (Fischhoff et al. 1982, Slovic 1999). Therefore, it is crucial to understand better how and why experts differ in the understanding and valuation of invasive species and their effects on ecosystem services and biodiversity.

We mapped the understanding of basic concepts commonly used to describe and explain biological invasions, and the ways experts value the risks and effects of biological invasions. To do this, we conducted 26 structured, face-to-face expert interviews. We used a qualitative approach because we were interested in elucidating the interrelated arguments, values and attitudes regarding biological invasions that are difficult to uncover through other methodologies. The experts belonged to two, equally sized groups, one of 13 invasion biologists and the other of 13 landscape experts. Both groups have a professional interest in ecological change, including the spread of non-native species; however, while plant invasions are the main focus of the work of invasion biologists, they are only one issue among many others in the work of landscape experts. By including landscape experts, we control for the convergence of perceptions in a scientific discipline, in this case invasion biology, that may be driven by an intra-scientific need to focus research (paradigm, Kuhn 1962) or the societal expectation for a profession to speak with one voice and act according to certain standards (Mieg 2009).

The overall aims of this interdisciplinary study (the authors include three biologists / environmental scientists and a risk psychologist) were: (i) to document the variability of the general conceptual understanding and the assessment of biological invasions among invasive species experts, (ii) to identify those aspects where the diversity of understandings and assessments among experts is particularly high and which therefore might account for dissent among invasive species experts, (iii) to investigate whether the consensus among invasion biologists differs from that among other relevant experts, and (iv) to identify possible explanations for any dissent among experts. We found that not only the framing of basic concepts (e.g., non-native or invasive) but also experts' thinking about the relevance of these concepts as well as the valuation of effects of NIS varied widely.

Methods

We used a qualitative research approach, which is often used in the social sciences to gain a multidimensional understanding of why individuals see the world in a particular way, and to explore the range of different thoughts, feelings, and interpretations of meaning of individuals in respect to an issue (Given 2008).

Study participants

The study was based upon face-to-face interviews with 26 academic experts with contrasting expertise in the broad field of ecological change. Prior to the interviews, these experts were assigned to two equal groups, one with a research focus on plant invasions (invasion biologists, IB, 9 males) and one with a research focus on ecological change in the landscape in general with plant invasions as one among many possible drivers (landscape experts, LE, 9 males). Landscape experts formed a heterogeneous group, including experts from agricultural and environmental sciences, biology, and geography (Appendix II). To avoid contingent differences in the use of terms such as native versus non-native in particular geographic regions (e.g., USA vs. Europe), we focused on a well-contained group of European experts. In Europe biological invasions have become a major concern for research and management only in the last decades, but currently invasive species research is one of the most active research areas in ecology in particular due to two large European research programs: ALARM (Settele et al. 2005) and DAISIE (DAISIE 2009). Given that invasive species are a fresh and very prominent topic, Europe is an ideal study system for understanding the diversity and dynamics of expert thinking. All experts were German speaking and the interviews were conducted in German, and they were all affiliated with an academic institution in Switzerland or Southern Germany. The experts were chosen to represent the major research groups at universities as well as applied research institutions in the study area that are working on plant invasions in terrestrial ecosystems. Some study participants were recommended by other experts. With the exception of four young scientists (3 IB, 1 LE), at the time of the interviews all participants had a long-standing record of major contributions to the literature on the issue of biological invasions and/or ecological change.

Structure of the interview guideline

We performed structured face-to-face interviews including closed and open-ended questions. A strength of this method is that it allows for a direct elicitation of individual understandings and valuations without the bias of social interactions in group settings possibly hampering the expression of extreme views or the recognition of individual uncertainties or lack of knowledge. Our interview guideline (Appendix I) was compiled following a literature search and a review of the inter-

national scientific literature on biological invasions, and especially plant invasions. We limited ourselves to the perceptions of ecological change caused by plants because a) plant invasions are particularly intensively studied and have driven most of the theoretical debates in invasion science (especially also in Central Europe), b) plants significantly shape ecosystem processes, and c) the analysis as well as the full acknowledgement of the debate about animal rights inherently linked to the issue of biological invasions by animals would go beyond the scope of this investigation. We focused on concepts that are of particular importance both in the scientific literature on biological invasions and the sociopolitical deliberations about the issue (non-native, invasive, ecosystem services). To finalize the interview guideline, we ran two pilot interviews with a geographer and an environmental scientist, respectively.

The interview guideline consisted of three main parts: in the first part (Q1–Q10), participants were asked about their understanding of key concepts (native, non-native, invasive). The second part focused on the valuation of effects of non-native, invasive plants on ecosystem services (Q11–Q12) (sensu Millennium Ecosystem Assessment 2005). Experts were presented 12 cards that listed various ecosystem services: two provisioning services (Biodiversity, Food), four regulating services (Climate Regulation, Human Health, Pollination, Protection from Natural Hazards), two supporting services (Primary Production, Soil Formation), and four cultural services (Cultural Heritage, Landscape Aesthetics, Sense of Place, Recreation / Tourism). The study participants then had to assess whether non-native, invasive plants have a predominantly negative, neutral, or positive influence upon the twelve ecosystem services, resulting in twelve separate assessments per expert. Additionally, experts were asked to briefly motivate their decisions. Before participants valued the effects of non-native, invasive plant species on ecosystem services (Q10) they were informed about the definition of an invasive species by the Swiss Commission for Wild Plant Conservation and Swiss federal legislation SR 814.911. However participants were also told that they are free to stick to their own definitions. In the third part, we focused on the invasive species issue as a societal problem. We asked the experts why they considered biological invasions to be a problem (Q13–Q15), confronted them with the problem understanding of the Swiss government (Q16), explored some key dimensions of the problem understanding in more detail (Q17–Q19), asked about the availability of sufficient scientific evidence (Q20), and asked for an assessment of the scale of the problem (Q21–Q25). Answers to questions Q20–Q21 and Q23–Q25 were measured on 5-point Likert scales. Additionally the participants were asked to motivate their decisions shortly. The interviews ended with questions seeking information on participants' current research (Q26) and basic demographic data (Q28, Appendix II). Further, experts were asked if they want to make a concluding statement (Q27). Before the start of the interviews, participants were informed about the general direction of our study, i.e., to elicit the perception of ecological processes related to non-native plants (see interview guideline, Appendix I). At the start of the interviews, all experts provided

verbal consent to audio record and transcribe their answers. Participants were ensured that after transcription, the data would be anonymized. All interviews were led by the first author.

Data analysis

All interviews, which mainly lasted for about one hour, were digitally audio recorded and transcribed verbatim in German. The interviews were performed between September and October 2009. In the case of the valuation of effects on ecosystem services (Q11), we were not only interested in the overall assessment (effect evaluated as positive, negative or neutral) by the experts but also in the types of arguments that they used to motivate their valuations. For this analysis, the authors identified different recurring arguments used by the study participants to motivate their valuations. A few questions (Q12, Q13–Q19) were omitted from the analysis because they yielded redundant data only. Questions Q20–Q21 and Q23–Q25 were closed questions, which allowed us to quickly gain information on specific attitudes experts held towards NIS and biological invasions in the societal context.

Results

Irrespective of the expert group (invasion biologists or landscape experts) we found diverging framings of key concepts related to biological invasions, varying valuations of effects of non-native, invasive plant species (NIS) on ecosystem services (ES), as well as differing understanding of, and attitudes towards biological invasions as a societal problem. We found a clear difference between the two expert groups for only a few questions, while within-group variation was generally high.

Understanding of key concepts

1. Non-native origin

Experts generally agreed that a non-native plant is a species that arrived in a certain geographic area through movement facilitated by humans. However, expert definitions differed in their temporal and spatial reference, and only some referred to environmental change or human perception. None of the experts mentioned any biological characteristics of a species, e.g., that a non-native species has different traits than a native species, as part of the definition of non-nativeness.

Landscape experts (LE) offered a greater diversity of definitions than invasion biologists (IB), and tended to discuss more explicitly their difficulties in defining a

non-native species. For instance, three LE emphasized that the choice of a spatial or temporal reference is a subjective decision:

[...] *there is no absolute definition of what is native and non-native.* [...] *what is new, say 10 or 20 years, this I would classify as non-native.* [LE8].

But also some IB argued that definitions are arbitrary:

The definition used is completely arbitrary [...] *This means in fact transitions are fluid and* [...] *if one would comprehend the definition in a broader sense, almost every vascular plant is non-native in Switzerland because they re-migrated after the ice age.* [IB8].

Temporal reference: Experts based their distinction between native and non-native species upon arrival time, using events in human history to define such temporal references. However, while invasion biologists mostly adhered to the same definition, landscape experts varied widely in their temporal reference (Fig. 1). Most invasion biologists (IB) defined non-native species as those species introduced after the year 1500 AD (i.e., Columbus' discovery of the Americas), usually adding that this is the accepted or official definition in the literature. However, many of them perceived this definition as somewhat arbitrary. Only three landscape experts (LE) referred to the year 1500 A.D., and five LEs did not address the time question; the other five LE proposed dates ranging from some unspecified time in the past, to the Neolithic period, the industrial revolution, and the period of globalization (Fig. 1).

Spatial reference: In contrast to a temporal reference, most experts used unspecific spatial references (e.g., "moved to here" or "moved to where we are"). Only 5 IB and 2 LE specified a spatial reference, basing this upon either human or biogeographical considerations. Thus, some referred to a political unit (such as "not from Switzerland", "not from Europe") while others mentioned biogeographical features ("from another continent", "from a different biogeographic area", or "from an area separated by topographic features (such as mountains or oceans) that hinder dispersal"). The various spatial references varied so widely that, applied to an area such as Switzerland, they would define strongly differing sets of non-native species.

Environmental change: Some experts, both LE and IB, acknowledged that natural or anthropogenic environmental change can affect what is considered to be a non-native species. Some went on to state explicitly that species dispersing to a new area in response to anthropogenic environmental change (esp. climate change) should also be considered non-native.

Human perception of the non-nativeness of a species: Some LE referred to human perception in their discussion of the definition of non-nativeness. One LE argued, for instance, that species present for a long-term are sometimes considered to be native by local inhabitants, while another LE specified that non-native species are those that arrived in an area over a period shorter than a human lifespan.

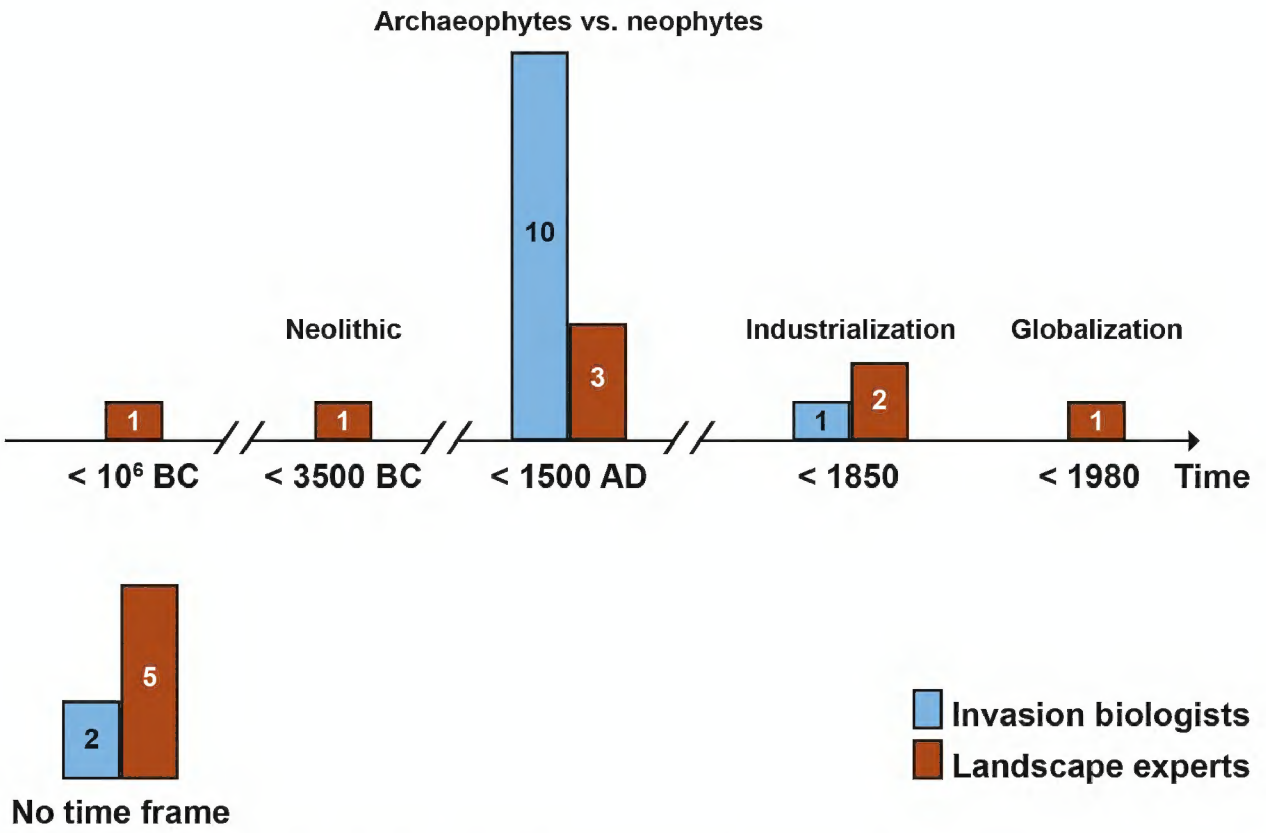

Figure 1. Contrasting conceptualizations of the non-native origin of a plant species in Central Europe. Invasion biologists mainly referred to the notions of archaeo- and neophytes and thus to the year 1500 A.D. to distinguish non-native from native species (blue boxes). Landscape experts referred to a wide range of different time frames, including no mentioning of any reference point in time (brown boxes).

2. Native species

To define a native species, most experts used similar considerations as for non-native species, but some experts used "presence since the last glacial period" as their criterion for a native species (3 IB / 2 LE). One invasion biologist pointed out that experts did not agree about whether to regard archaeophytes, i.e., species moved to Europe by humans before 1500 A.D. (Fig. 1) as native or as non-native. Thus, as for non-nativeness, nativeness of a species was mainly related to both its geographical distribution and to the period it was present in an area (Fig. 1); however, some experts also referred to biological characteristics, mentioning that native species are likely to be adapted to the local conditions (especially climate). Correspondingly, some experts mentioned that a native species evolved in a place, and others raised the possibility that a species can be native to a particular climate zone in mountains. Contrary to criteria used to define non-nativeness, only one LE discussed environmental change, and no-one considered the possibility that human perception might have a bearing upon a species' native status.

3. Invasive species

After clarifying the terms native and non-native, we asked our participants whether native and non-native plants differ in their behavior. Experts agreed that such bio-

logical differences are not inevitable (9 IB / 9 LE), though some regarded them as likely (3 IB / 7 LE). In this connection, the following characteristics of non-native plants were mentioned: i. novel interactions with or dominance of resident organisms due to a lack of coevolutionary history, ii. adaptation to fast or human-related dispersal, and iii. the possession of novel traits enabling species to occupy an empty niche. In general, however, experts explained that the question was "difficult to answer", due to "insufficient scientific information", or "high complexity", meaning that "evaluations must be done on a case-by-case basis". Ambiguity among experts became particularly obvious in how they related the non-nativeness and the invasiveness of species: some experts spontaneously valued the behavior of non-native plant species as problematic (4 IB / 5 LE), while others did not mention an invasive behavior at all.

We then explicitly asked our participants for a definition of a non-native, invasive plant species (NIS). Experts generally agreed that an NIS is one that spreads spontaneously and rapidly, and exerts a negative impact on native species, ecosystem processes, the economy, or human health. Two experts (1 IB / 1 LE) stated explicitly that the term invasive does not necessarily imply a negative impact. To them, range expansion alone was a sufficient condition for being an invasive plant species.

Valuations of effects on ecosystem services

Each expert was then asked to value the influence of NIS in Europe on twelve different ecosystem services (ES) as negative, neutral or positive, resulting in twelve separate assessments per expert. Eight of the ES can be regarded as provisioning, regulating, or supporting services, and four as cultural services. For every ES there were some negative, neutral, or positive assessments, and in general both IB and LE ranged widely in their assessment of the effects of NIS on ES (Fig. 2). In total, experts made more neutral valuations (56%) than negative (32%) or positive ones (12%). Our study participants perceived the strongest negative impacts of NIS on ES Biodiversity (56% negative valuations) and ES Cultural Heritage (54% negative valuations). Most favorable effects of NIS were attributed to ES Landscape Aesthetics with 33% positive valuations. On average, invasion biologists (IB) tended to assess the effects of NIS upon ecosystem services more negatively than landscape experts (LE), especially for ES Cultural Heritage, Sense of Place, Food, and Soil Formation (Fig. 3).

We were particularly interested in how experts reached their opinions concerning the influence of NIS on ES, and the arguments they used to substantiate them. We identified four issues characterizing various uncertainties that complicate the valuation process: 1. how to deal with a lack of empirical information; 2. how to deal with value judgments; 3. what to do when the same species has both positive and negative effects; and 4. how to treat the non-nativeness of a species in value judgments.

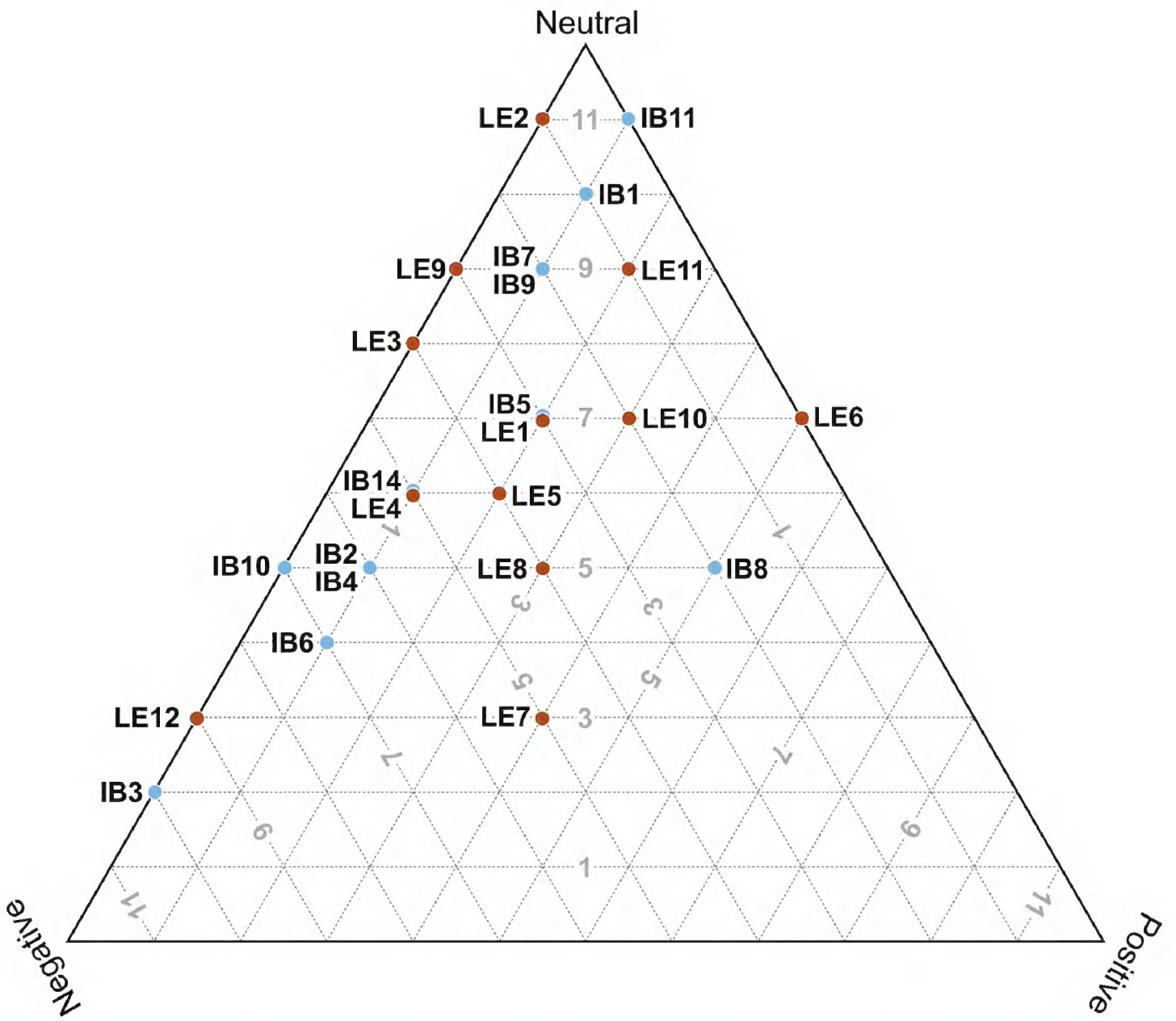

Figure 2. Number of positive, neutral, and negative assessments of the predominant effect of not further specified non-native, invasive plant species on 12 different ecosystem services for 12 invasion biologists (IB1-IB11, IB14, blue dots) and 12 landscape experts (LE1-LE12, brown dots). The perpendicular distance of the parallel lines to the respective corner corresponds to the number of positive, neutral, and negative assessments of a study participant (e.g., LE7: 3 neutral, 5 negative, and 4 positive assessments).

1. Decision making with limited information

Experts consistently mentioned a lack of empirical information about effects of NIS on ES. At best experts knew about documented effects of one to a few particular species. Information about effects caused by a broad range of different invasive species, however, was mostly missing. We identified five ways through which experts coped with this uncertainty: (i) concluding that there were no effects of NIS on ES, (ii) acknowledging the lack of empirical information, (iii) extrapolating from their knowledge about the effects of particular species, (iv) building on general knowledge about effects of NIS on certain ES, or (v) referring to the frequent overabundance of NIS, that is often stated as a specific characteristics of NIS in the literature, and deriving predictions about effects from this general pattern.

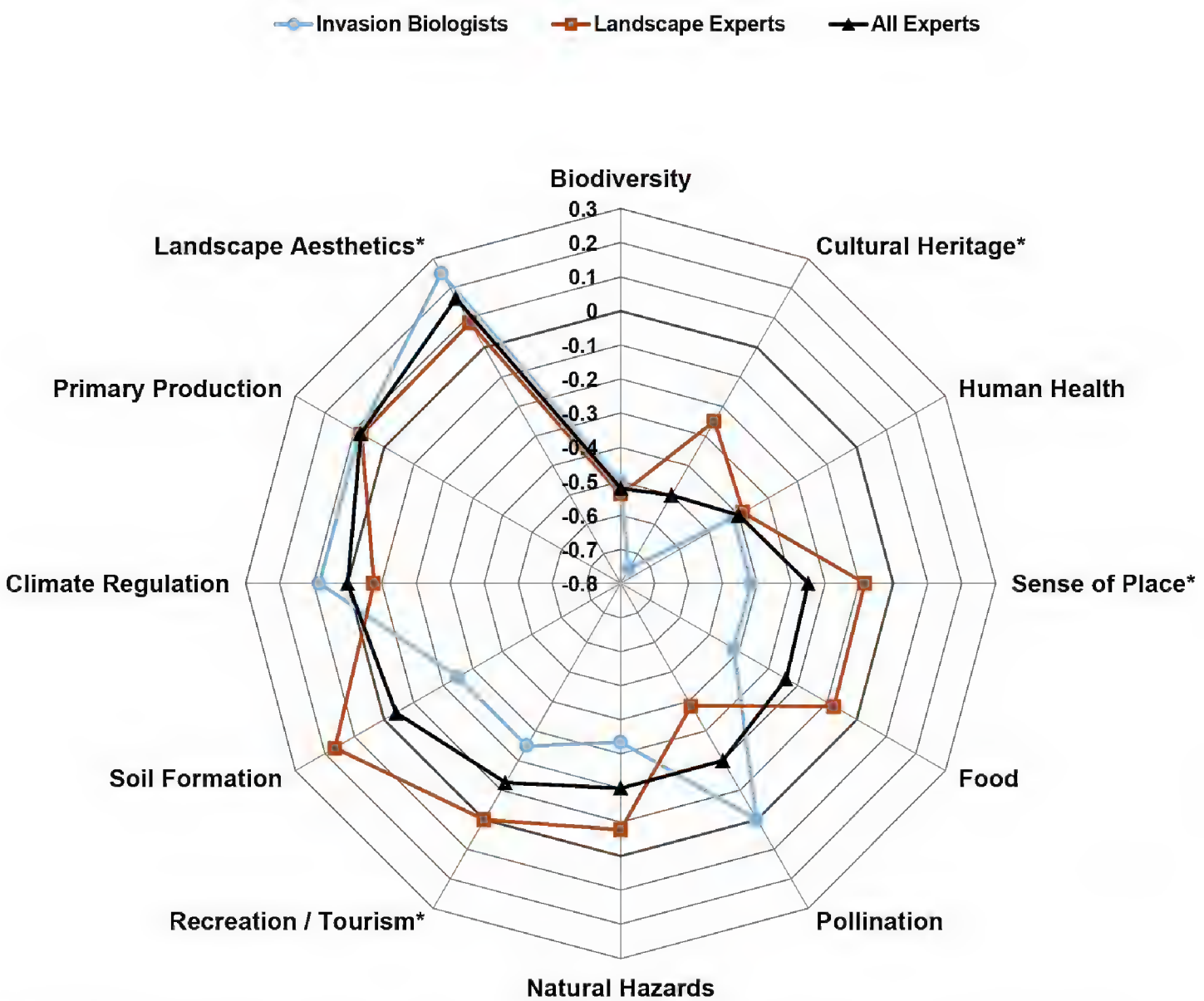

Figure 3. Average valuations of the effects of non-native, invasive plant species (NIS) on different ecosystem services (ES). On average, invasion biologists (blue dots) assessed NIS effects on ecosystem services (ES) more negatively than landscape experts (brown squares), particularly in the case of cultural ES (asterisks). The overall mean of the evaluations (black triangles) is most negative for ES Biodiversity and most positive with respect to ES Landscape Aesthetics.

Acknowledged lack of knowledge (*i, ii*): In almost a third (32%) of all assessments, experts could not recall any effects of NIS on ES. The experts drew one of two conclusions from this lack of knowledge: either that NIS have little or no effect compared with native species, or that important information was missing (either to them as an individual expert or more generally in the literature). Some experts suggested that more research on the subject is needed. But otherwise, with very few exceptions only, experts assessed neutrally in both cases.

Extrapolation from information about particular species (*iii*): Sometimes experts based their assessments on well-known effects associated with particular species, such as *Solidago* sp., *Ambrosia ambrosiifolia*, *Heracleum mantegazzianum*, *Reynoutria* sp. and *Impatiens glandulifera*. In particular, experts recalled the adverse impact on human health of *A. ambrosiifolia* and *H. mantegazzianum*, and the destabilizing effects of *Reynoutria* sp. on soil in general and particularly on stream banks. But experts also em-

phasized e.g., the attractiveness of flowers of *Solidago* species. Some experts concluded from these examples that other invasive species may have similar effects, while other experts emphasized that extrapolation is not possible.

Extrapolation from general knowledge about NIS (*iv*): In some cases experts felt confident to make general statements about NIS effects on ES. These statements were based on generalized knowledge about NIS without reference to particular species. For instance, an expert explained the negative impact of NIS on ES Biodiversity, arguing that "globally NIS were the second most important cause for a decrease of biodiversity" [IB5]. Such generalizations were common for statements about effects on ES Biodiversity: most experts were prepared to assume that NIS have a generally negative effect upon native biodiversity, though few explained the underlying mechanisms or cited empirical evidence. Most experts generalized at least once (9 IB / 10 LE).

Reference to overabundance (*v*): The only general characteristic of NIS that was explicitly mentioned to substantiate general claims about effects of NIS on ES was the fact that invasive species often form dense stands. For all ES except ES Human Health at least one expert recognized overabundance as a reason for negative impact. Overabundance was most frequently stressed in the context of ES Biodiversity, Pollination, and the cultural ES Cultural Heritage and Sense of Place. Overabundance of NIS always led to a negative valuation and was the basis for one third (34%) of all negative valuations.

2. Explicit consideration of values and value judgments

Valuation of an effect entails understanding how an NIS changes an ecosystem property, and then assessing whether this change is positive or negative. Experts rarely explicitly mentioned the second step, and the importance played by values. In particular, experts assumed that the preferred state of non-cultural ES (and associated cultural views or ethical values) was clear and uncontroversial, the only exceptions being for ES Pollination and Food (2 IB). In contrast, for assessments of NIS, influences on cultural ES, more often value judgments were made explicit. All experts except for three (1 IB / 2 LE) stated at least once either their own feelings or values towards NIS or their effects (9 IB / 9 LE), or they referred to feelings or values of particular stakeholder groups (e.g., tourists, agriculture, general public) (8 IB / 10 LE). Experts remarked for instance that because of positive experiences with a particular NIS their sense of place was "positively connected" to the presence of that species; on the other side, they spoke of "negative feelings" towards "change in a familiar landscape", or "getting irritated by monocultures", and "being distressed" by negative impacts of some NIS on recreation. Interestingly, however, explicit consideration of personal values or different stakeholder views was less prominent for ES Cultural Heritage.

Some experts acknowledged that valuation of stakeholders is rooted in cultural history. LE6 for instance considered NIS effects on ES Cultural Heritage as positive and explained:

It is positive because...the fact that plants were moved to particular places is part of our culture, whether we consider it positively or not. [LE6]

LE3 referred to the evolution of perceptions over time:

If one accepts that over time invasive plants [...] *become a cultural heritage, then it is not negative.* [LE3]

Similarly conifers that were extensively planted in Switzerland during the 19th century were recognized by one LE as a "kind of invasion at the time" [LE2] but were perceived today as enhancing landscape aesthetics. However, only few experts elaborated more generally on the value-laden nature of assessing effects on cultural ES.

3. Ambiguous valuations

All experts except 5 LE emphasized the difficulty of valuating effects in situations where a species has both positive and negative effects on different or even the same ES; or when different people value the same effects differently. LE3, for instance, argued that while invasive species might reduce biodiversity in the short term, they might lead to a higher, new biodiversity in the longer term. Or, LE11 valued the influence of NIS on ES Landscape Aesthetics neutrally and commented:

Related to landscape aesthetics it's a matter of taste - there are people who are enthusiastic about dense Solidago stands, but from the point of view of nature conservation it's rather negative. [LE1]

4. The role of non-nativeness in valuation of effects on ecosystem services

The non-nativeness of a species was used both in value judgments and to explain how the species might affect ecosystem services. It was not always evident whether the non-nativeness of a species was valued in itself or as a reason for expecting some negative impact. Non-nativeness was mentioned in the context of all ES, but was not considered equally important by all participants.

Particularly in the context of ES Cultural Heritage, experts described a sense of loss associated with the spread of NIS - for example, "loss of a landscape" they had been used to or "loss of identity" as the result of the presence of a non-native species; similarly, experts mentioned their feeling that the "new species did not belong" to their culture. Thus, some experts considered the presence of non-native species in itself as negative for cultural heritage:

Invasive, non-native plants have to be negative, because they are new and not native, and so not part of our heritage. [IB2]

Several experts implied that valuing the non-nativeness of a species depends on knowing which species are non-native and which ones are not. IB9 for instance argued that:

Most people do not have any idea of what is indigenous und what is non-indigenous. Hence they [invasive plant species] *do not have any influence on the recreational factor at all.* [IB9]

In other cases, the novelty of non-native species was positively valued – for example, when the species was seen as "an enrichment" of the preexisting flora or a "contribution to the aesthetic value" of a landscape.

Biological invasions as a societal problem

To reveal experts' evaluations of how serious they consider the problem of NIS in Central Europe to be, we asked a series of quantitative questions (Fig. 4). All participants recognized NIS as a problem in Central Europe, although most rated it as small to medium at present (Fig. 4A). Yet almost all experts expected problems related to NIS to increase in the future (Fig. 4B), emphasizing anthropogenic environmental change as a driver of future invasion threats. Especially IBs called for action against NIS through concrete management measures (Fig. 4C). Most participants of both expert groups agreed that our causal understanding of why some plants become a problem is inadequate (Fig. 4D), arguing, for example, that the complexity of ecosystem processes makes general assessments difficult or even impossible. Interestingly the two expert groups clearly diverged in their assessment on how the problem is recognized by a particular stakeholder group of their choice (Fig. 4E). In general, invasion biologists considered that the problem was underestimated by the public and in politics. Landscape experts tended to see the problem as overestimated, particularly due to anxiety and xenophobic feelings among the public.

Discussion

Our interviews with experts of plant invasions and/or ecological processes in the landscape indicate that their understanding of the phenomenon of non-native plant invasions is diverse and influenced by individual conceptualizations, beliefs, and values. While we expected a rather high diversity of perspectives in the heterogeneous group of landscape experts, we were surprised by the lack of consistency in the use of basic concepts amongst invasion biologists, since the research field is well defined, and its leaders have invested much effort in standardizing key concepts (e.g., Colautti and McIsaac 2004, Valéry et al. 2008, Colautti and Richardson 2009, Pyšek et al. 2009, Richardson et al. 2011). In fact, the diversity of perceptions within both experts groups was so large that for most issues we examined there was no clear difference between

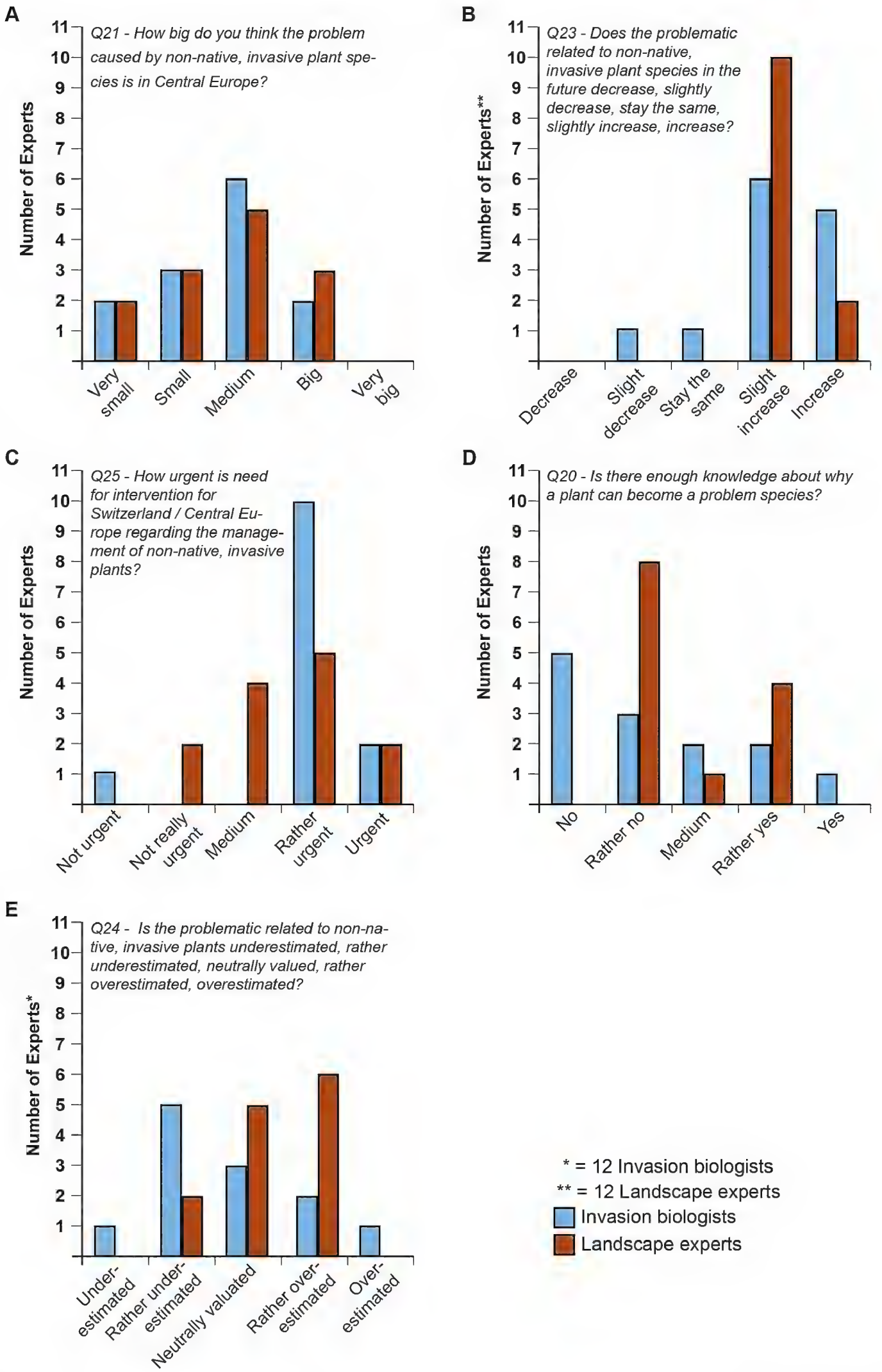

Figure 4. Experts' responses to a set of closed questions regarding the invasive species issue as a societal problem (Appendix I, Q20–Q25). Blue boxes: invasion biologists, brown boxes: landscape experts.

the groups. Our study was restricted to German-speaking experts of Switzerland and Southern Germany, and an even higher diversity of expert opinions might be expected if we had included a broader geographical range. Studies from other regions indicate that many of the relevant dimensions of expert thinking that we identified for German-speaking Europe might also be relevant elsewhere (Selge et al. 2011, Young and Larson 2011). We suggest that the heterogeneity of expert judgments observed in our study is related to three major dimensions: (1) diverging understandings of basic concepts, (2) complexities and contingencies of biological invasions, and (3) valuation uncertainties with respect to the qualitative assessment of the effects of non-native, invasive plant species on ecosystems and their services.

Diverging understandings of basic concepts

Central to any understanding of a non-native, invasive species (NIS) are the definitions of non-native and invasive species. Many of our participants accepted, at least in part, conventional definitions widely used in the research field, though the interviews also revealed more diverse thinking. We screened the publications of the participating invasion biologists to check whether the results from the interviews were also reflected in the ways experts used definitions in their scientific publications. We found that authors generally reported a definition of a non-native and invasive species in the introduction or methods section of a publication, but in the rest of the text this definition was rarely strictly applied. For instance, authors might present a definition that distinguishes between non-native and invasive species, but then use the terms interchangeably in the text; or they might compare invasive non-native species with native species without specifying whether or not the native species are also invasive (fast spreading / having a negative impact). This tension between a shared definition and a much broader understanding of key notions is also more generally apparent in the biological invasion literature. Indeed, many of the difficulties in operationalizing definitions of non-native and invasive species that we uncovered in this study can be found scattered throughout the literature (Garrott et al. 1993, Shrader-Frechette 2001, Brown and Sax 2004, Sagoff 2005, Warren 2007, Davis 2009, Valéry et al. 2009, Rotherham and Lambert 2011, Young and Larson 2011, Webber and Scott 2012).

Given that the definitions of an NIS can be regarded as core elements of the paradigm of the research field (e.g., they are introduced in every textbook), it is surprising that we found such a high diversity of alternative understandings among experts. Even among invasion biologists only two thirds mentioned a common temporal reference for the definition of the non-nativeness of a species (1500 A.D., Fig. 1) and only half explicitly stated that non-native species are those moved through human-assisted dispersal. And landscape experts did not agree at all on a common temporal reference. There was also no agreement on other aspects necessary for a non-ambiguous definition of an NIS, such as where a species must come from to count as non-native, and some important aspects were not mentioned at all, in particular how to determine

whether a species is fast spreading. This aspect, although basic to the definition of NIS, is difficult to operationalize and several different approaches are described in the literature (compare Richardson et al. 2000, Wilson et al. 2009, Sorte et al. 2010, Webber and Scott 2012). In fact, the different answers given by the experts lead to substantially different selections of non-native and invasive species. Experts also differed in their understanding of what a native species is, despite the extensive literature on this topic in Central Europe (Schroeder 1968, Webb 1985, Kasparek 2008). In summary, we found uncertainties related to at least eight conceptual dimensions that affect a common understanding of the key notions of a non-native species and an invasive species: (i) minimum and maximum residence time in a new area, (ii) source area, and (iii) dispersal pathway (through human agency or not) of a non-native species; (iv) What counts as human-assisted dispersal? (v) Must an invasive species be fast spreading and/or have a recognized negative impact? How are (vi) fast spread and (vii) negative impact defined? And, (viii) should the term invasive be reserved for non-native species or also be used for native species?

In many cases, differences between experts' definitions reflected different ways of framing a socioecological problem. In particular, some experts understood invasions primarily as a biological phenomenon, while others approached it as a sociocultural phenomenon. According to the biological perspective, the non-native origin is important because species introduced into new areas often exhibit distinctive ecological behavior, with respect to both the source population and to the native flora where the species establishes. A non-native species may, for instance, behave differently from a native species because it is released from its natural enemies (Keane and Crawley 2002), or has novel traits that are not present in the native flora (Vitousek et al. 1987). In contrast, some landscape experts approached the subject with primarily a sociocultural perspective in mind. Thus, they placed emphasis upon the temporal dynamics of human perception of and cultural attachment to nature and biodiversity, or different important historical episodes such as the beginning of industrialization or globalization as the basis for separating native and non-native species (Fig. 1). Interestingly, ecological and sociocultural types of reasoning were often intermingled. For instance, while most invasion biologists indicated that they intended to gain an ecological understanding of why non-native species behave differently from native species, most of them nevertheless referred to a cultural criterion for separating non-native from native species, namely the year 1500 A.D. Thus, a cultural definition of the non-nativeness of a species is used in an ecological argument.

The notion of a non-native, invasive species as a boundary object

Several authors in the invasion literature have expressed confidence that the problem of conceptual pluralism in research on biological invasions can be overcome by defining key notions more precisely (Colautti and McIsaac 2004, Pysek et al. 2004, Valéry et al. 2008, Colautti and Richardson 2009, Pyšek et al. 2009, Richardson et al. 2011,

Webber and Scott 2012). However, experience in invasion biology and other fields of ecological research indicate that it is difficult to establish precise definitions that all experts can share (e.g., Shrader-Frechette 2001, Haila 2002, Sagoff 2005, Hodges 2008, Moore et al. 2009). The situation is further complicated by the fact that through anthropogenic environmental change, patterns and processes are changing so fast, with the consequence that concepts and research approaches must be continuously adapted (Kueffer 2013). In the case of complex and interdisciplinary problems, therefore, it may not always be possible to reach a consensus on definitions. There is probably no way to avoid a melting pot of diverse terms and perspectives characteristic of an increasingly inter- and transdisciplinary invasion science. It is clearly important for authors to define their key terms in a particular context, but even this may not help much; a better solution may be to classify alternative definitions of concepts that are valid for particular purposes (Hodges 2008).

It may even be that partially ambiguous terms can be beneficial for the research field by facilitating inter- and transdisciplinary dialogue. For this to occur, they must serve as boundary objects, meaning concepts that have a similar but not identical meaning to different expert groups (adapted from Star and Griesemer 1989). Thanks to this fluidity, these concepts can facilitate collaboration between different communities because they can be adapted to different specialized expert discourses without losing a shared core meaning. Indeed, our data shows that the term non-native, invasive species encompasses a range of different meanings that resonate with different research interests, an observation that is also reflected by the diversity of perspectives in the literature on invasive species (compare e.g., Davis 2009, Richardson 2011, Heger et al. 2013b, Fig. 5). For instance, biogeographers are interested in the role of geographic barriers in determining species distributions and richness patterns, and non-native species – defined as species that cross biogeographic barriers – resonate with their interests. Some evolutionary biologists and ecologists are interested in how species respond to novel abiotic and biotic conditions and, in turn, how species with novel characteristics can change ecological processes. For them, it is less important whether a species is from another biogeographic area, but it matters whether it introduces some form of ecological novelty to a system. Invasions offer a suitable system for population and community ecologists to study the processes of spread and colonization, but these do not necessarily differ between non-native and native species. Overabundance of some NIS is a feature that they share with some native winners of anthropogenic change, which can be unrelated to biogeographic origin or processes of spread (e.g., Fig. 1 of Rejmánek 2000). In turn, scientists from the social sciences and humanities are interested in, for instance, the cultural connotations of the terms invasive and non-native (and associated terms), and in human-nature relationships and how these influence the geographic distribution and human perception of species. In management, NIS are also addressed differently in contrasting realms, such as transnational biosecurity policies vs. the local management of natural areas. For biosecurity policies the non-native origin of species is central, while origin may be of lesser importance for local ecosystem management.

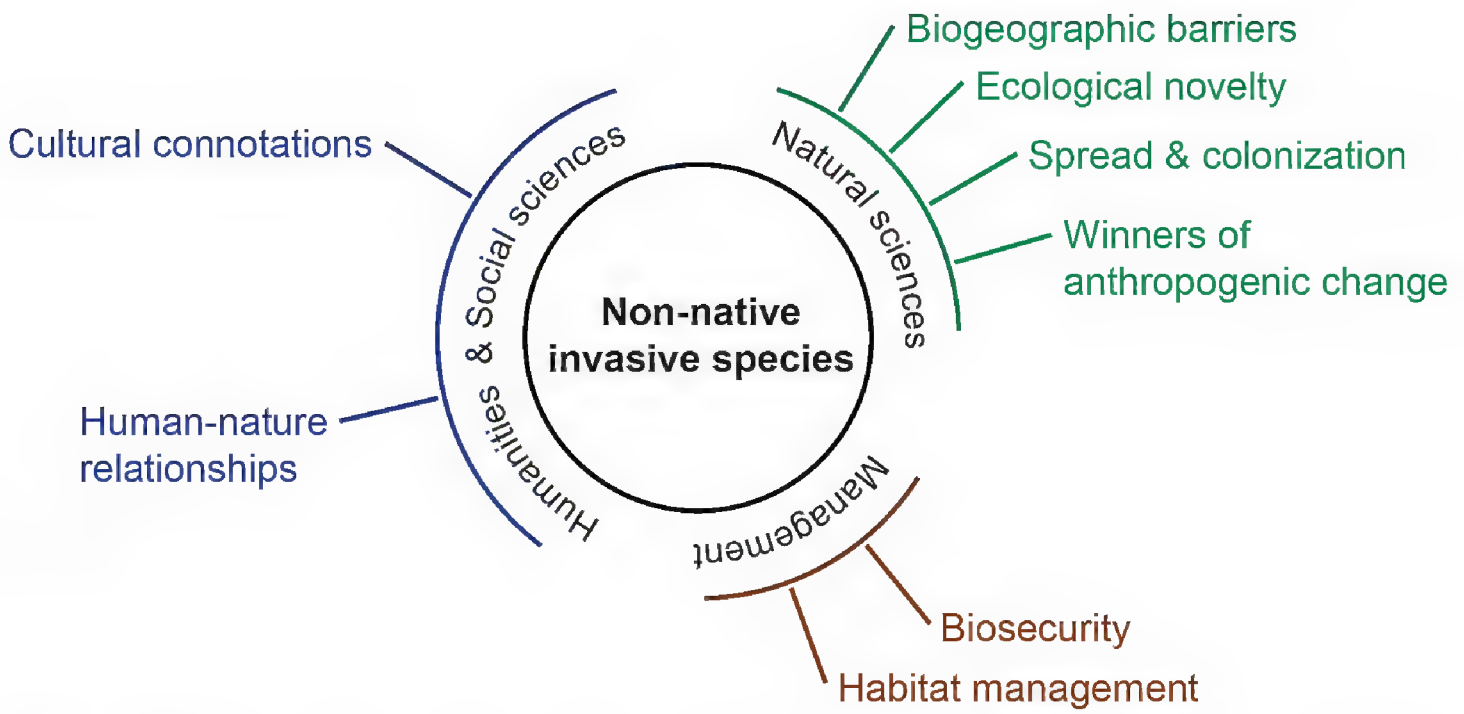

Figure 5. The notion of a non-native, invasive species (NIS) as a boundary object: different groups of experts use the same notion with a different specific meaning and purpose in different contexts. Thereby the notion of an NIS as an ill-defined concept can help to facilitate collaboration across these diverse experts group (see main text for further explanation).

Of course, the pluralistic usage of concepts also bears risks. For instance, the sometimes vigorous conflicts between social and natural scientists related to the invasive species issue (e.g., Simberloff 2003, Raffles 2011) may have arisen from a failure to recognize that they were using the same term to mean different things. Social scientists, accustomed to deliberations about the cultural connotations of terms like alien or non-native, accuse invasion biologists of being xenophobic (which is a legitimate concern within the narrow boundaries of their specialized debates), though biologists use the term in a very different context and usually without any cultural connotations. It is therefore important to carefully reflect on the different contexts when using terms such as non-native (or alien, exotic, foreign, etc.) in science or policy.

Complexity and contingencies impede proactive action

Most participants stressed that risk assessments of biological invasions are made difficult by our lack of basic understanding of the important processes. In more than 50% of the assessments of effects of NIS on ecosystem services, experts decided for a neutral assessment, saying that potentially unknown effects or lack of knowledge prevented them reaching any other conclusion. They also often pointed to the complexity and contingencies of biological invasions, emphasizing that factors such as habitat context and anthropogenic disturbances interact, and that the dynamics and outcomes of invasions can change in time. In particular, they emphasized the difficulty of making general statements across many species and contexts, especially when considering the

longer-term spatio-temporal dynamics of ecosystems. The only general characteristic regularly used by experts to legitimate their valuations of effects was the overabundance of an invasive species; while in almost all other cases they were forced to extrapolate effects from individual NIS to all invasions. Such extrapolation - from individual cases to invasions in general - is also widely used for predicting the potential effects of NIS in the literature (e.g., Pimentel et al. 2000).

We designed our interviews in a way that forced experts to make general statements to mimic their expert role in decision-making processes. Due to the emphasis of current invasion policy upon proactive action, in particular measures to prevent potentially problematic non-native species from being introduced (Leung et al. 2002, Hulme 2009), decisions often have to be taken for species that are not well known or only from other areas. Thus, there may be considerable uncertainty in determining whether or not a non-native species poses a risk (without in-between categories) across all habitats. Many experts in our interviews stated that such extrapolation from a few, often poorly known case examples is problematic, thus echoing a strong critique of invasive species management by philosophers of science (Shrader-Frechette 2001, Sagoff 2005). Alternative approaches to biosecurity that might circumvent this problem include adaptive management processes, participatory methods, or risk assessments that are specific to particular habitats or introduction pathways (e.g., Kueffer and Hirsch Hadorn 2008, Liu et al. 2011, Hulme 2012).

Valuation uncertainty influences risk perception and risk assessments

The process of risk assessment is also complicated by uncertainties related to the valuation of effects of NIS. In our study we found at least three different kinds of valuation uncertainties: (i) ambiguous endpoints for risk assessments, (ii) differing value systems or perceptions, (iii) the role in value judgments of controversial concepts such as non-nativeness.

A first valuation uncertainty – ambiguous endpoints of risk assessments – became obvious when our study participants stated that the same invasion can simultaneously lead to several outcomes - some positive, others negative. For instance, according to the experts *Solidago* species can provide an important food source for native pollinators and at the same time out-compete native plant species. About one quarter of all neutral assessments reflected such ambiguities.

Second, valuation options may vary among experts and stakeholders depending on their value system and perception. For example, in assessing the contribution of *Solidago* species for the landscape, some may value the yellow flowering in late summer positively, while others will negatively value the fact that the landscape differs from what they consider to be a natural landscape. Especially for cultural ecosystem services, experts emphasized that valuation depends on the affected stakeholders that are considered.

Third, specific to the invasive species debate is the use of the native vs. non-native species dichotomy (Fig. 1). Not surprisingly, the controversial perception of the importance of a species' origin for risk assessments added as a third factor to the hetero-

geneity of expert valuations. Most participants agreed in principle that invasive species should be judged according to their effects on native biodiversity and ecosystems, and not by their origin, i.e., their non-nativeness per se. Many experts therefore stressed the need to distinguish clearly between non-native and invasive species. This corresponds with the way lay people value invasive species, with detrimental impacts being more important than biogeographic origin (Fischer and van der Wal 2007, Selge and Fischer 2010). Nevertheless, invasion biologists are regularly criticized for condemning non-native species solely because of their foreign origin (Larson 2007, Davis et al. 2011). Indeed, despite their intention not to use non-nativeness as a value, many experts revealed an implicit bias against non-native species in their answers to interview questions. This was especially evident when valuing cultural ecosystem services such as Cultural Heritage, Sense of Place, or Landscape Aesthetics, with several experts treating the presence of non-native species negatively because of their non-nativeness. Whether and how non-nativeness is used to make value judgments adds to valuation uncertainty, especially because this criterion is often not explicitly mentioned.

The problems of multiple effects and multiple adequate values are widespread in environmental problem solving, and there is a broad literature on multi-criteria and participatory valuation and decision-making methodologies (Scholz and Tietje 2002). However, such methods have rarely been applied in the context of invasive species (Binimelis et al. 2007a). Indeed, established procedures such as risk screening systems or black lists (Pheloung et al. 1999) do not consider the possibility of the context-dependence of effects and conflicting valuation, and new approaches are only now being developed (Randall et al. 2008, Hulme 2009, Liu et al. 2011, Kumschick et al. 2012, Dahlstrom Davidson et al. 2013). Similarly, media communications rarely represent the diversity and uncertainty of valuation of NIS (Chew and Laubichler 2003, Larson 2005).

Speaking with one voice to the public: an outdated expectation from invasive species experts?

In our study, expert opinion diverged strongly in questions concerning the effects of non-native, invasive plant species (NIS) on individual ecosystem services (Fig. 2 and 3), and the assessment of the problem posed by these species in Europe (Fig. 4). This divergence of opinion revealed in interviews contrasts with the broad consensus on the risks and effects of biological invasions that experts claim in scientific synthesis articles and policy documents (Mack et al. 2000, Millennium Ecosystem Assessment 2005, DAISIE 2009, Hulme et al. 2009, Vilà et al. 2010). Indeed, the invasion biologists in our survey have all published articles concerning plant invasions in Central Europe in which they state that biological invasions lead to major biodiversity loss and/or economic costs. In most cases, however, these statements were of a general nature and supported by data from outside of Europe (citing e.g., Pimentel et al. 2000, Mooney et al. 2005).

One possible interpretation for this paradoxical situation is to consider the dual nature of an expert as on the one hand a person with a high degree of knowledge of a

subject and on the other hand someone with a special role in certain decision-making situations attributed by society (Mieg 2009). Invasion biologists are faced with the difficult challenge of reconciling high uncertainties in internal expert deliberations (i.e., in their role in producing new knowledge) with their public role as experts, expected to speak with one voice to decision-makers and the public. This situation is even more complicating when a consensus is needed for action to minimize future risks but the knowledge upon which to base this action is uncertain or missing. Indeed, while disagreeing on the current severity of the problem, both invasion biologists and landscape expert tended to agree that the severity of the problem will increase and intervention is urgent (Fig. 4).

Nevertheless, recent examples of conflicting debates among invasive species experts played out in the media (Davis et al. 2011, Simberloff et al. 2011) suggest that such accord may not be possible in the future. It is questionable whether speaking with one voice is even desirable: in the context of climate change, Curry (2011) argues that pressure to achieve consensus may have led the Intergovernmental Panel on Climate Change (IPCC) to oversimplify some issues of high uncertainty, thereby hampering the formulation of appropriate policy decisions; and similar concerns have been raised in the context of biodiversity conservation (Turnhout et al. 2012). An alternative to seeking consensus would be for invasion biologists to acknowledge the uncertainties and to engage transparently with stakeholders and the public in deliberations about conflicting opinions (Larson et al. 2013) or diverging management priorities (Bayliss et al. 2013). Here invasion biologists should take the role of "honest brokers of policy alternatives", taking into account different prevalent values and policy preferences, rather than adopting the role of "issue advocates" (Pielke Jr. 2007, Sarewitz 2011).

Conclusions

Our results uncovered a high diversity of perspectives within and between two expert groups, invasion biologists and landscape experts, on how to frame and to value biological invasions. Such dissent is in strong contrast with the broad consensus that experts claim in scientific synthesis articles and policy documents (e.g., Millennium Ecosystem Assessment 2005).

We propose that dissent among experts arises for many reasons, and multifarious solutions are therefore needed to improve the situation. First, irreducible uncertainties and contingencies should be acknowledged and taken into account in invasive species research and risk assessments (Hulme 2012, Jeschke et al. 2012, Heger et al. 2013a, Kueffer et al. 2013, Larson et al. 2013). Second, rather than attempting to establish precise definitions for key concepts such as 'non-native' or 'invasive' that all experts can share, it may be better to recognize explicitly alternative definitions that are valid for particular purposes (Hodges 2008, Heger et al. 2013a, Heger et al. 2013b). It can be argued that many conflicts about invasive species between social and natural sciences have arisen from a failure to recognize that different disciplines may use the same term

to mean different things. Third, the process of risk assessment is complicated by uncertainties related to the valuation of effects of non-native invasive species. The problems of multiple effects and multiple adequate values are widespread in environmental problem solving, and there is a broad literature on multi-criteria and participatory valuation and decision-making methodologies. Such approaches should be applied in invasive species risk assessment, management, and communication. Lastly, invasion biologists have differing views of the appropriate role for experts in societal decision-making, and especially the degree to which they should advocate particular viewpoints (Young and Larson 2011). Our results indicate that invasion biologists, rather than claiming to represent a consensus when none exists, should engage transparently with stakeholders in deliberations about conflicting opinions and alternative concepts, thereby adopting the role of "honest brokers of policy alternatives" (Pielke Jr. 2007, Sarewitz 2011).

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Appendix I

Questionnaire. (doi: 10.3897/neobiota.20.6043.app1) File format: Microsoft Word Document (docx).

Explanation note: Interview guideline: perception / valuation of ecosystem change related non-native, invasive plants.

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Questionnaire S1. NeoBiota 20: 1–30. doi: 10.3897/neobiota.20.6043.app1

Appendix II

Socio-demography of the study participants. (doi: 10.3897/neobiota.20.6043.app2) File format: Microsoft Word Document (docx).

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Socio-demography of the study participants. NeoBiota 20: 1–30. doi: 10.3897/neobiota.20.6043.app2